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STANFORD ELECTRONICS LABORATORIES

RADIOSCIENCE LABORATORY
STANFORD, CALIFORNIA

24 April 1963

Admiral Paul A. Smith
RAND Corporation
1000 Connecticut Avenue, N.W.
Washington, D. C.

Dear Paul;

This is further to my recent letter to you giving my reactions to our very interesting and--for me--worthwhile trip to Alaska.

I enclose herewith for your information a memorandum prepared by my colleagues Eshleman and Peterson, describing certain scientific information which could be obtained by use of a standby transmitter at the Clear, Alaska, BMEWS site.

I will be interested in your reaction to this memo. If the proposal seems reasonable, should we circulate it to other Geophysics Panel members, and consider the possibility of bringing it to the attention of the Air Force through the SAB?

Sincerely yours,

Mike

O. G. Villard, Jr.
Professor

OGV/p

Enclosure

cc: V. R. Eshleman
A. M. Peterson

THE STANFORD CENTER FOR RADAR ASTRONOMY

Radioscience Laboratory of Stanford University
Radio Physics Laboratory of the Stanford Research Institute

PRELIMINARY PROPOSAL FOR THE USE OF THE CLEAR, ALASKA BMEWS RADAR FOR MAGNETOSPHERIC SOUNDING AND FOR COMMUNICATIONS EXPERIMENTS BASED ON FREE ELECTRON SCATTER

We suggest that there are several experiments that could be conducted using a standby BMEWS radar transmitter with present or new antennas which would: (1) provide important basic information about the upper atmosphere to a height of several thousand kilometers, and provide radar clutter data which would be of fundamental importance in the design of more sensitive defense radars; and (2) test the feasibility of a new low-data-rate communications mode which promises to be more reliable and secure in the face of natural and man-made interference than HF and ionospheric scatter communications modes.

I. Magnetospheric Sounding

Density fluctuations of thermal electrons in the ionospheric and magnetospheric plasma scatter electromagnetic waves at somewhat less than the intensity expected due to incoherent Thomson scattering. The complex spectrum of the scattered energy at radio wavelengths is controlled largely by ion dynamics, and the details of the spectrum, together with the intensity of scattering, yields information about the number density of electrons and ions, the electron and ion kinetic temperatures, and the ionic constituents.

With a powerful pulsed radar system, these parameters can be studied as a function of height, time of day, and season of the year.

A 50-Mc, 5-Mw peak power transmitter and 1000-foot square array of dipole antennas has just come into full operation in Peru at the magnetic equator. This system, operated by the U. S. National Bureau of Standards, has already been used to make electron density profile measurements to a height of 8000 km, where the electron density is on the order of 1000 cm^{-3}. It is expected that profiles to 30,000 km height can be measured with this system. A 400-Mc, 2.5-Mw peak power transmitter and a fixed 1000-foot spherical dish antenna is being built in Puerto Rico by Cornell University and the U. S. Air Force for such magnetospheric sounding experiments, and for other radar astronomy studies. A 440-Mc, 2.5-Mw peak power transmitter and an 85-foot steerable paraboloid has been used by the Lincoln Laboratory of MIT to make density and spectral measurements to a height of about 1000 km. This transmitter has recently been used with a fixed 220-foot paraboloid to study in detail the diurnal changes of the electron and ion temperatures at the peak of the F region (about 300-km height). The Stanford Center for Radar Astronomy (SCRA), a joint group from Stanford University and the Stanford Research Institute, hopes to obtain a 400-Mc, 600-kw average-power transmitter for use with the steerable 150-foot paraboloid for use with the steerable 150-foot paraboloid for magnetospheric sounding (and other studies), with particular emphasis on the predicted effects of the terrestrial magnetic field on the scatter spectrum.

The first suggestion regarding the feasibility of magnetospheric radar sounding was made only four years ago. The very intensive experimental and theoretical efforts that have been made in exploiting this technique in this short time give evidence as to its potentialities for basic studies of the upper atmosphere. In looking over the present plans for experimental sites, it appears that there is an important omission, since the auroral zone is not represented. Yet it is at these latitudes that the important solar plasma and radiation-belt interactions with the atmosphere are most pronounced.

During the 1963 Space Science Summer Study held at the State University of Iowa, magnetoshperic sounding was strongly endorsed as one of the ground-based endeavors which should receive strong support from NASA, and the need for an auroral-zone site [illegible] stressed. While the potentialities of this technique appear to merit the construction of a new research radar near the auroral zone, it seems that the aims of such a research program could be realized for less cost if one of the standby transmitters at the BMEWS site at Clear, Alaska, could be used with a new, vertically-beamed antenna for such studies. In addition to the fact that the transmitter is already available, it should be noted that the BMEWS radar frequency is nearly optimum for magnetoshperic sounding, and that the scientific results of such a study program are cirtically needed to assess basic clutter-echo limitations to phased-array defense radar systems which are being proposed for constructio[illegible] the present BMEWS sites.

The bandwidth of the electron scatter echoes varies as λ^{-1} over the radio wavelengths of interest, while the cosmic noise background varies approximately as $\lambda^{2.3}$. Realizable receiver noise temperatures are approximately constant over the band of interest. For a fixed aperture transmitting and receiving antenna, and a fixed radar pulse width, the scattering volume varies as λ^2. Taking these factors into account, and assuming cosmic noise equals receiver noise at $\lambda = 1m$, the optimum (for highest signal-to-noise ratio) wavelength for magentospheric sounding, is about 0.9m. Over the range of likely values of cosmic noise and receiver noise temperatures, the optimum wavelength varies between about 0.5 and 1.5 meters. BMEWS radar systems operate within this optimum range.

Methods of upgrading defense radar systems are being studied to increase range and decrease the minimum detectable target size. Very powerful systems appear to require a large number of separate transmitters driving separate fixed antenna elements, with beam slewing being accomplished by means of phase control on the transmitters.

It appears that ionospheric and magnetospheric scatter echoes may constitute the effective noise level of such systems over an appreciable part of the range and spectrum within which targets are to be sought.

While preliminary estimates can be made of these effects, it would appear to be of great importance to make whatever experimental measurements are feasible near the latitudes of the sites of the proposed new radar systems. The present equatorial research radar can provide much of this information for low latitudes. With regard to the auroral latitudes, a research effort using a present BMEWS transmitter and a new antenna could provide information on the nearly incoherent scatter associated with a thermal plasma to heights of several thousand kilometers. In addition, it is possible that the ionosphere and magnetosphere during auroral disturbances will produce more nearly coherent scattering at much greater intensities. It is known from work with relatively low-power radars that when the antenna beam is normal to the magnetic field, the echoes may increase 50 db or more above thermal plasma scattering. A careful study with a very sensitive radar is needed to determine if any such coherent effects are present for other beam directions during disturbed times.

II. Communication Potentialities of Scattering from the Ionospheric Thermal Plasma

The same scattering phenomenon described above shows promise of providing a new mode for reliable, but low data-rate, communications. We suggest that a study of this mode could be made, for example, by using one of the present BMEWS standby transmitters at Clear, Alaska, together with a new antenna beamed southwest, and with a new and similar receiving antenna at the Stanford radio field site. The path length would be about 3600 km. which is near optimum for this type of communications. In addition, the proposed SCRA 400-Mc transmitter would permit two-way communications experiments. As with magnetospheric sounding, the present BMEWS transmitter and proposed SCRA transmitter both operate near the optimum wavelength for this type of scattering. Long range and reliable communications from BMEWS sites is, of course, of great operational importance.

The special features of this type of scattering for communications applications include:

1. The scattering medium is provided by nature. It is always present to some degree, and it is invulnerable.

2. Long distance communication is almost as efficient as communication over shorter distances, with 4000 km representing a good design distance. Tha range may be extended to 5000 km or even further at reduced capacity.

3. A wide band of frequencies can be used, with 100 to 1200 Mc being the likely region of application.

4. Natural SID's will probably not disrupt the signal, and man-made blackout effects will be effective only for a very short time. Following this period the signal should be even stronger than normal.

5. The intersection region of the beams can be chosen at will in three dimensions, as compared to zero dimensions for a communication satellite and essentially one dimension for an orbiting belt of passive scatterers.

6. The earth's magnetic field affects the signal spectrum in a complicated manner whenever the incident and scattered rays make equal angles with a field line. These spectral characteristics may lead to methods of increasing the capacity of the circuit, and they may provide inherent AJ potentialities.

The special disadvantages are:

1. The high cost of the required transmitters (megawatt size) and antennas (areas on the order of 1500 square meters) for an estimated average capacity of about one hundred teletype channels (one channel being 60 wpm or 25 bits per second, with an error rate of $1:10^3$). Such installations would, of course, be suitable only for fixed point-to-point communication.

2. The capacity of the channel would be expected to vary from 1/10 to 10 times the average capacity as the density of the F layer changes with time of day, season, and sunspot number. The average capacity would be higher in equatorial regions, and lower in polar regions, than at middle latitudes.

3. Because of the width of the scatter spectrum, efficient communication often requires a sort of "package deal" on the number of channels that are used. For example, if 100 channels can be supported by 1 Mw, it does not necessarily follow that one channel can be maintained with 10 kw. It could require as much as 100 kw for one channel under these conditions.

More complete information on this proposed communications mode is included in an addended report.

Von R. Eshleman
Allen M. Peterson
26 November 1963